Compact Reliable Robust (CORE) Power System for Auxiliary Power Applications

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ABSTRACT

Under support from TARDEC, an effort to develop a 10 kW$_e$ compact reliable robust power system for combat-vehicle applications is well underway. This system operates on battlefield-spec JP-8 to provide silent auxiliary power for the vehicle. The reformer converts JP-8 into a hydrogen rich reformate. The power system combines the reformer with a High-Temperature PEM (HTPEM) fuel-cell stack that retains the quick startup time of a PEM fuel-cell stack while dramatically improving the tolerance to fuel impurities to levels closer to that of SOFC stacks. The paper covers the power system development with the emphasis on the 300-hour demonstration of the 10 kW$_e$ reformer operating on JP-8 and its current integration with the fuel cell to produce the 10 kW$_e$ power system for 1000 hour demonstration and delivery to TACOM.

INTRODUCTION

A fuel-cell based power system can meet the Army's ground-vehicle APU demands while maintaining silent-watch capability. The main challenges in developing such an APU are 1) conversion of JP-8 to an ultra-low-sulfur hydrogen-rich reformate and 2) utilization of a robust fuel-cell stack that can undergo rapid startup. Under TARDEC support, the development team has overcome these challenges in developing a complete 10-kW$_e$ JP-8-to-power solution.

Under Segment I, which ran from May 2006 to May 2008, the team developed and demonstrated the compact reliable robust reformer that converts JP-8 to an ultra-low-sulfur hydrogen-rich reformate, thus overcoming the first challenge noted above. The reformer meets the requirements listed in Table 1.

Under Segment II, the Altex-led team is integrating the reformer with CEP's robust High-Temperature PEM (HTPEM) fuel-cell stack to produce the 10-kW$_e$ JP-8 driven APU system. The 160°C operating temperature of the HTPEM fuel-cell stack retains the quick startup time of a PEM fuel-cell stack and its robustness while dramatically improving its tolerance to fuel impurities – closer to levels for SOFC stacks. This tolerance has been demonstrated by JP-8-to-power tests, of which some are presented in this paper. Also, the stack robustness has been demonstrated by thousands of hours of field tests conducted by CEP on pre-production natural-gas-fired systems.

This system is being fabricated for delivery to TARDEC after a 1,000 hour demonstration. This paper summarizes the results of Segment I and some of the activities of Segment II.

The power system builds upon and contributes to the proven desulfurizer and reformer systems that have been delivered for independent testing. Presented in Figure 1a is a photograph of a SOFC reformer that was delivered to Army Research Laboratory (ARL). Presented in Figure 1b is a photograph of the 2 kW$_e$ reformer for HTPEM that was delivered to CERDEC. The combination of the experience gained from delivering these reformers, the use of a HTPEM fuel-cell stack, and transitioning to a microprocessor-based control system enables the production of a compact and robust JP-8-driven APU system that can start within half hour from cold conditions.

Table 1: TARDEC Segment I requirements.

Parameter	Key Requirements
Power Capability	10 kW$_e$ (net) 28 VDC ± 2 VDC
Application	Operational brass board
Fuel	JP-8
Fuel Sulfur Content	400-3000 ppm$_w$
Fuel Aromatics	10-14%
Turn-Down Ratio	10:1
Operating Temperature	Ambient 'lab' temperatures
Durability	300 hours
Start Up Time	30 minutes
Reformate Flow	12-120 SLPM H_2
Reformate Sulfur Level	Less than 1 ppmv

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14. ABSTRACT
Under support from TARDEC, an effort to develop a 10 kWe compact reliable robust power system for combat-vehicle applications is well underway. This system operates on battlefield-spec JP-8 to provide silent auxiliary power for the vehicle. The reformer converts JP-8 into a hydrogen rich reformate. The power system combines the reformer with a High-Temperature PEM (HTPEM) fuel-cell stack that retains the quick startup time of a PEM fuel-cell stack while dramatically improving the tolerance to fuel impurities to levels closer to that of SOFC stacks. The paper covers the power system development with the emphasis on the 300-hour demonstration of the 10 kWe reformer operating on JP-8 and its current integration with the fuel cell to produce the 10 kWe power system for 1000 hour demonstration and delivery to TACOM.

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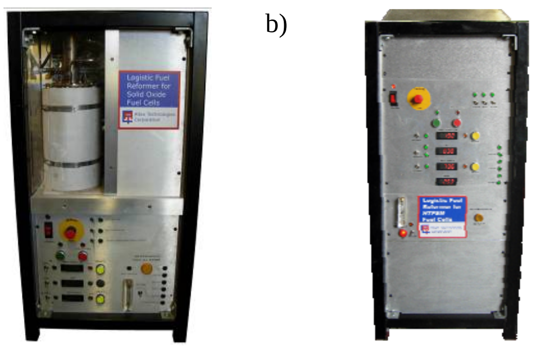

Figure 1: a) Reformer for SOFC delivered to ARL; b) Reformer for HTPEM delivered to CERDEC.

Reformer Development and Testing

To control the risk of converting the JP-8 fuel to a hydrogen-rich reformate, the reformer consists of two subsystems, a fuel preprocessor (FPP) and a fuel processor (FP). Each subsystem is designed to attack specific issues with reforming the fuel [1,2,3,4]. The FPP removes sulfur and the majority of carbon-producing compounds in the fuel and diverts them to a burner to produce heat needed by the reformer system. The FP converts the FPP-cleaned fuel into a reformate suitable for use in a HTPEM fuel-cell stack.

During Segment I of the program the materials needed for the FPP and FP were identified and/or developed followed by qualification for the full-scale system. Sample data from these material-qualification activities are presented in Figure 2. Presented in Figure 2a are data from the qualification of the regenerable adsorbent that is used in the FPP. This material was continuously improved to meet the program targets and, as shown, the material met the system target for at least 300 system-hours. Presented in Figure 2b are data from the qualification of the main catalysts utilized in the FP for nearly 600 hours.

Similar to material development, the system components were developed, qualified, and integrated to produce the 10-kW_e reformer. As per program requirements, the system was demonstrated for 300 hours following a test plan that was developed with TARDEC.

Tests were conducted using TARDEC-supplied JP-8. These fuels included a baseline fuel with 525 ppm_w sulfur and a high-sulfur fuel with 625 ppm_w sulfur. Table 2 lists key characteristics of these fuels. It should be noted that this system is designed to operate on field-spec JP-8 that can contain up to 3,000 ppm of sulfur. However, during Segment I, no source of JP-8 with higher sulfur content was identified in US. A source of JP-8 with 2,700 ppm_w sulfur has been identified, and the system will be tested with this fuel during Segment II of the program. Segment I tests of the reformer included rigorous shakedown, load-variation, turn-down, and longevity tests. In particular, the system demonstrated full-scale operation (10 kW_e) and over 10:1 turn-down (<1 kW_e).

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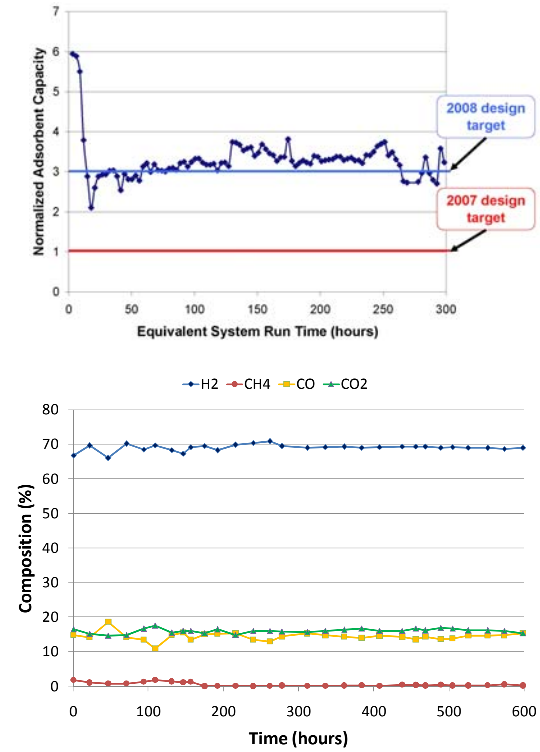

Figure 2: Key materials longevity testing. Ahead of system integration a) Regenerable adsorbent for sulfur removal b) prereformer/reformer catalyst.

Presented in Figure 3 are the longevity test data. The data are plotted as the equivalent fuel-cell power corresponding to the flow of H_2 produced by the reformer over the 300-hour longevity test. The data presented in Figure 3b are the inlet fuel sulfur and the reformate composition (H_2 and CO). As shown, during the first 50 hours the system was tested on JP-8 with 625 ppm_w of sulfur followed by 250 hours of testing on the baseline JP-8 fuel with 525 ppm_w of sulfur. Despite the differences in the level of sulfur in the parent fuel and the planned load variation, the reformer produces a constant composition of 75% H_2 and 1% CO. This composition is compatible with the CEP HTPEM fuel cell.

Table 2. JP-8 properties used to demonstrate the reformer

TARDEC-Supplied Fuel	Sulfur (ppm_w)	Total aromatics (Mass %)	Poly-aromatics (Mass %)
Baseline JP-8	525	20.5	1.9
High-Sulfur JP-8	624	19.0	2.0

a)

b)

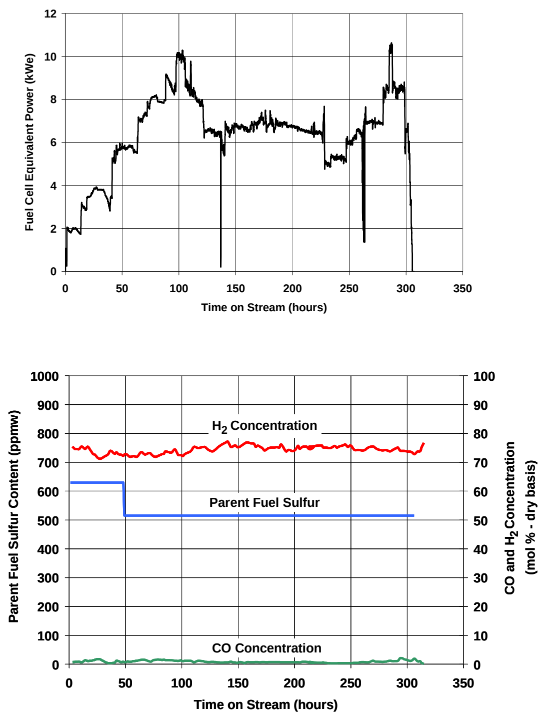

Figure 3: System longevity testing. a) Reformer load; b) Sulfur content of the parent fuel and of the intermediate streams.

As shown in Figure 3a, the unit was started at a load of 2 kW_e and increased stepwise to 10 kW_e for the first 100 hours of testing. It was then brought down to a baseline load level of 6-7 kW_e. The system was operated at the baseline load level for about 100 hours (between hours 125 and 225). The unit was paused briefly at around 135 hours due to an unrelated facility-maintenance activity. What appears to be noise in the data at around 260 hours is transient-load testing.

The data from this transient-load testing are presented in Figure 4. This test, based on the original test plan, was to demonstrate the turndown from baseline load (6-7 kW_e) down to a low-level load (0.5 kW_e) within a timeframe of about 30 minutes. As shown in Figure 4, the first three cycles were performed at a rapid frequency of about 5 minutes. The time for the FP system to ramp up from about 0.5 kW_e to 7 kW_e was about 2 minutes. The other 5 cycles were performed at a slower, controlled rate, taking about 25 minutes to ramp up from a low-level load to the baseline-level load. This test demonstrates the rapid response of the system and the potential to match fast load-following requirements when the reformer is operated with the HTPEM fuel-cell stack. These data along with data from

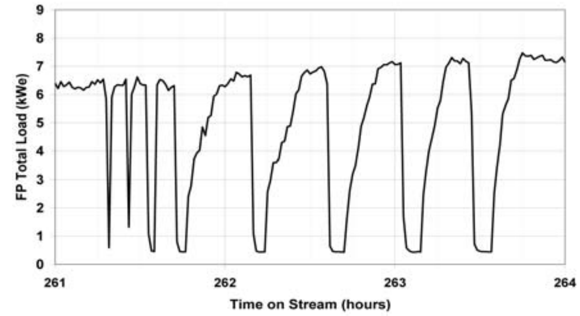

Figure 4: System longevity testing. Transient testing.

other tests demonstrate that the reformer is capable of over 10:1 turndown ratio.

These successful tests demonstrated that the reformer meets the TARDEC requirements and can convert JP-8 to a hydrogen-rich reformate stream suitable for generating power in a HTPEM fuel-cell stack.

System Power Development and Testing

Upon successful demonstration of the reformer and conclusion of the Segment I, Segment II was initiated. Under this segment, the reformer is being integrated with the fuel-cell stack. These activities include control-system development and miniaturization, BOP selection and qualification, water-recovery-system integration for water-neutral operation, and thermal integration for an efficient heat recovery. For example, all of the selected pumps and blowers have been qualified for at least 1,500 hours, and the control system is being miniaturized by transitioning to a microprocessor-based control system. Sample data from a fuel-pump-qualification test are presented in Figure 5.

The power system is water neutral. To this end, a water recovery system (WRS) has been developed that recovers the needed water for its water neutrality. To be water neutral the WRS has to recover 75% of the water exiting the stack. Presented in Figure 6 are data that demonstrate that the WRS

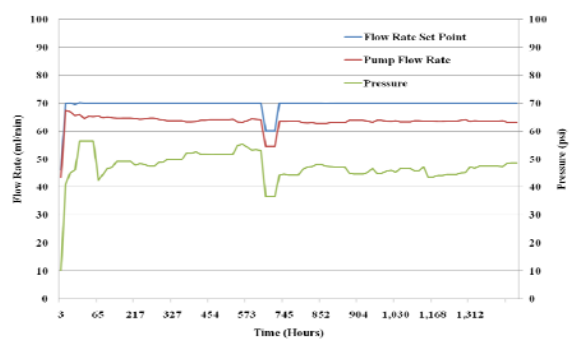

Figure 5: Sample Pump Longevity Test data.

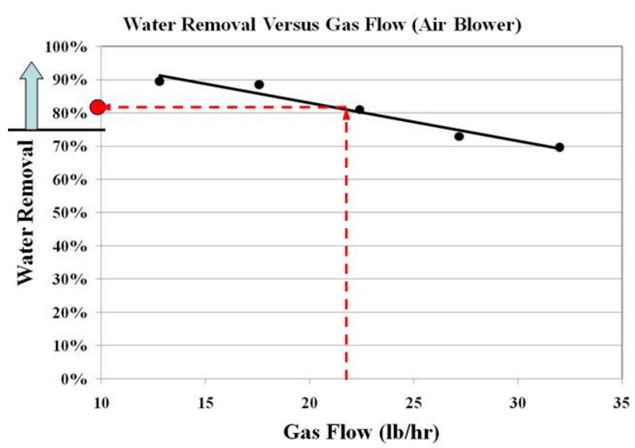

Figure 6: Water recovery system recovers sufficient water for a water neutral power system.

recovers over 80% of the water. The WRS is being integrated into the power system.

Before full integration of the stack, a short stack and the full stack have been operated with the reformer operating on JP-8 and other fuels to cover several power programs. Initial testing demonstrated steady power generation from JP-8 for over 50 hours with a 0.5-kW$_e$ short stack. The data presented in Figure 7 show stack power and the reformate CO level. These data show that the fuel-cell stack exhibited no degradation of performance and that the HTPEM fuel-cell stack allows production of consistent power from a reformate stream with as much as 1% CO and 0.1-0.5 ppm sulfur. Similarly, the reformer has been used to qualify a 5-kW$_e$ stack delivered by CEP.

This stack has been tested on reformate made from JP-8, diesel, and biodiesel in the reformer. The data in Figure 8 shows sample results from operation on diesel fuel. These

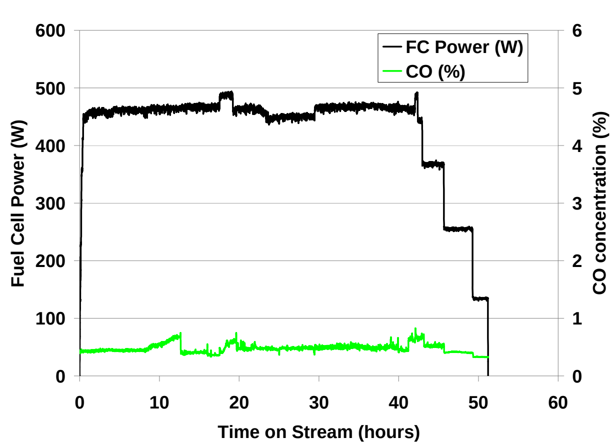

Figure 7: System operation on JP-8.

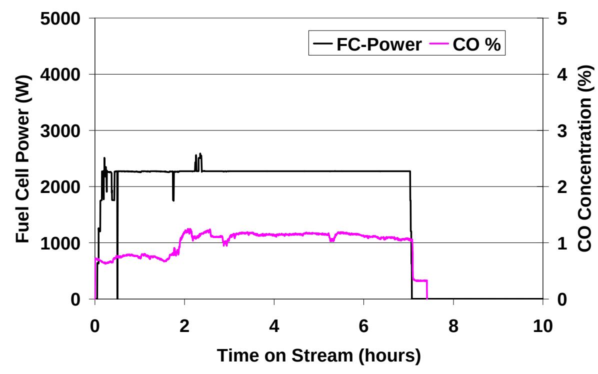

Figure 8: System operation on diesel fuel

tests show that the reformer can operate on a variety of logistic fuels.

The tests discussed above and others not discussed here are leading to the full integration of the power system, the 1,000-hour demonstration of JP-8-to-power, and delivery of the system to TARDEC for independent testing.

Summary and Conclusions

The 10-kW$_e$ reformer was demonstrated for 300 hours on TARDEC-supplied JP-8 with over 10:1 turn down and consistent production of reformate with 75% hydrogen and around 1% CO. This reformer is being integrated with a fast starting and robust HTPEM fuel-cell stack for producing the 10 kW$_e$ power APU for delivery to TARDEC after a 1,000-hour demonstration test. As such, the two challenges discussed in the introduction have been overcome making a fuel cell based Ground Vehicle APU realizable.

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